Performance of Optical Burst Switching Techniques in Multi-Hop Networks

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Abstract −In this paper, we investigate the performance of reservation mechanisms for optical burst switching (OBS) in multiple hop network environments. We first review current research on wavelength reservation schemes for OBS, and investigate the path length priority effect of existing just-enough-time (JET) scheme. And then, we propose a novel hop-by-hop priority increasing (HPI) scheme. The simulation results showed that the proposed scheme can avoid the path length priority effect and enhance the end-to-end throughput in multiple hop network environments.

I. INTRODUCTION

The rapid growth of the Internet has resulted in an increasing demand for transmission capacity in core backbones. As the growth of these demands out paces the capabilities of electronic switches and traditional transmission techniques, core networks must evolve to new architectures based upon all optical switching and dense wavelength division multiplexing (DWDM) technologies. Optical burst switching (OBS) has been proposed as the technology basis for such an all-optical Internet [1]-[3]. OBS combines the benefits of optical circuit switching and optical packet switching and, as such, it maintains the efficiency of optical packet switching while reducing the implementation complexities.

In OBS, the bandwidth for a data burst is generally reserved in a one-way process. That is, the source sends the control packet on a separate channel in order to reserve the bandwidth of the data channel, and then transmits data burst without waiting a confirmation for a successful reservation. Since control packets are converted to the electronic domain for processing and there are delays involved in setting up the optical switching matrix in each core node, one must carefully coordinate the timing of control and data planes. Generally, the compensation for the processing time of the control packets can be implemented using an offset time (OT) based scheme or a fiber delay line (FDL) based scheme [1]-[2]. In addition, wavelength reservation schemes in OBS core nodes can be classified as either immediate reservation (IR) [3] or delayed reservation (DR) [1] schemes.

Recently, various wavelength reservation schemes for OBS have been proposed, including the just-enough-time (JET) [1], the terabit burst switching mechanism [2], and the just-in-time (JIT) signaling developed under the ATDNet (formerly MONET) project [3]-[4]. In particular, the JET scheme has two features of OT-based scheme and DR scheme.

In the OT-based scheme, bursts with a different number of remaining hops to their destinations have different offset times that decreases as the burst traverses each OBS node. In the DR scheme, larger offset times result in lower burst blocking probabilities [5]. Therefore, in the OT/DR-based scheme, a burst with more remaining hops to its destination will experience a lower burst blocking probability than a burst with fewer hops. This coupling between remaining path length and blocking probability results in what is effectively different priority classes for reserving wavelength of a specific link. In this paper, we call this problem the *path length priority effect*. Furthermore, due to this path length priority effect, the burst blocking probability increases as a burst traverses the OBS nodes, resulting in the degradation of the end-to-end throughput.

In this paper, we investigate the path length priority effect of the OT/DR-based schemes like the JET protocol, and show that an FDL-based scheme can avoid the path length priority effect in multiple hop network environments. Then, we propose a novel FDL/DR with hop-by-hop priority increasing (HPI) scheme in order to enhance the end-to-end efficiency. Through simulation, we compare the performance of the proposed scheme with the existing schemes in terms of the burst blocking probability and the end-to-end throughput.

The remainder of the paper is organized as follows. Section II reviews and classifies the wavelength reservation schemes for OBS. Section III investigates the path length priority effect of the OT/DR-based scheme like the JET protocol, and Section IV proposes the FDL/DR with HPI scheme. Section V evaluates the performance of the proposed scheme and the existing schemes by simulation. Finally, some concluding remarks are presented in Section VI.

II. COMPARISON OF OPTICAL BURST SWITCHING TECHNIQUES

In an OBS transit network, the data packets from access networks are collected and classified by edge nodes according to their destinations and quality of service (QoS) requirements. Packets in the same class are then assembled into larger data units, so-called bursts, and transmitted across the network along an all optically switched path. Before such transmissions can occur, the source sends a control packet on a separate control channel in order to reserve the bandwidth of the channel for data burst. Since the control packet is converted to the electronic domain for processing and setup the switching matrix in each core node while data burst is kept in the optical domain, it requires compensating the processing time of the control packet and the switch setup time.

Generally, the compensation for the processing time of the control packet and the switch setup time can be implemented using an OT-based scheme or an FDL-based scheme as shown in Fig. 1, where S and D denote the source host (or router) and the destination host (or router) respectively, and δ indicates the processing time of the control packet plus the switch setup time at a core node. The OT-based scheme computes, at the source node, an offset time T for each control packet based upon the estimated sum of the processing times for the control packet plus the switch setup

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(a) OT-based scheme   (b) FDL-based scheme

Fig. 1. Basic concept of the burst transmission in OBS.
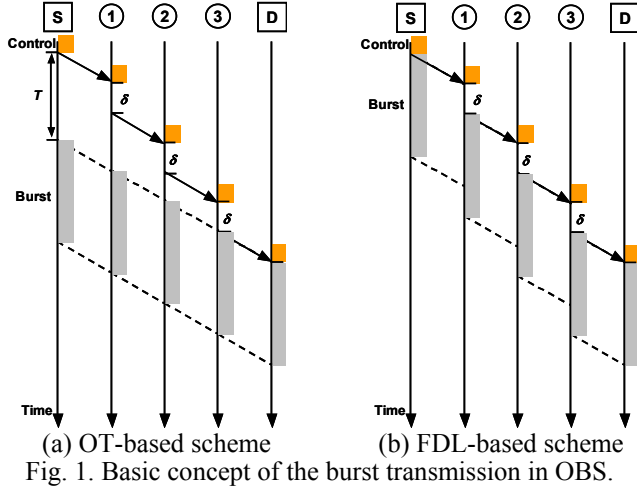
times at each core node on the path [1]. That is, the transmission of data burst is delayed at the source node by the basic offset time T after transmitting its control packet. Because the burst is buffered at the source in the electronic domain, no FDLs are necessary at each intermediate node to delay the burst while the control packet is being processed. Meanwhile, in the FDL-based scheme, data burst is immediately transmitted after transmitting control packet and the processing time of the control packet plus the switch setup time is compensated by delaying the data burst at each core node using an input FDL [2].

Typically, the FDL-based scheme is more complex to implement because it requires input FDLs at core node. However, the OT-based scheme has other complexities in their operation. In the OT-based scheme, the source node must know the complete path routing information of a data burst in order to calculate the basic offset time. Moreover, protection and restoration algorithms must more carefully select a backup path so that the number of hops for the backup path does not exceed that of primary path. If the number of hops for the backup path exceeds that of primary path, wavelength of a certain downstream nodes cannot be reserved because of the lack of remaining basic offset time. The Table I compares the characteristics of the OT-based scheme and the FDL-based scheme.

Wavelength reservation schemes in OBS core nodes can be classified as either IR [3] or DR [1] schemes according to the reservation time. In an IR scheme, wavelength reservation starts immediately after processing of the control packet finishes. In a DR scheme, the wavelength for a data burst is reserved starting from the time at which the burst is expected to arrive. An IR scheme can be implemented with low complexity because the only state information that must be

TABLE I
CHARACTERISTICS OF THE OT AND FDL-BASED SCHEMES.

	OT-based scheme	FDL-based scheme
Routing information requirements at source node	Yes	No
FDL requirements at core node	No	Yes
Protection/restoration complexity	High	Low

TABLE II
CLASSIFICATION OF WAVELENGTH RESERVATION SCHEMES FOR OBS.

|		Compensation for the processing time of the control packet	
		OT-based scheme	FDL-based scheme
Channel reservation	Immediate reservation	JIT	Terabit burst switching
	Delayed reservation	JET	

maintained in a node is whether a wavelength is currently available or not. However, a drawback of IR scheme is its reduced efficiency [6]. However, a DR scheme can improve efficiency by reserving a channel only during actual burst transmission time. Moreover, a DR scheme can support multiple classes of service by using an extra offset time. In order to support multiple classes of service, an additional QoS offset time can be assigned for higher priority classes thus permitting a higher priority burst to reserve resources in advance [5].

Table II shows classification of representative wavelength reservation schemes for OBS according to the previously defined categories.

III. PATH LENGTH PRIORITY EFFECT OF THE OT/DR-BASED SCHEME

The JET scheme has two features of OT-based scheme and DR scheme. In an OT-based scheme, bursts with more remaining hops to their destinations have larger offset times, and in a DR scheme, the larger the offset times, the lower the blocking at any given node [4]. Therefore, when an OT/DR-based scheme like the JET protocol is used, we observe a path length priority effect where burst blocking probability is a function of its proximity to its final destination. In effect bursts have different priority classes in reserving wavelength of a specific link according to the number of remaining hops to their destinations.

Fig. 2 shows an example in which the path length priority effect can occur in the OT/DR-based scheme. If bursts A and B have the same number of hops to their destination node, they will have the same length of basic offset time at each source node. We assume that bursts A and B contend for wavelength reservation on a core node as shown in Fig. 2. In this case, since the burst A traversed more core nodes, its residual offset time will be less than that of burst B. Hence, even though they start at their respective source nodes with the same basic offset time, the burst closer to its destination node will have a relatively lower priority in contending for the wavelength.

Fig. 2. Different residual offset times according to the number of remaining hops in the OT-based scheme.
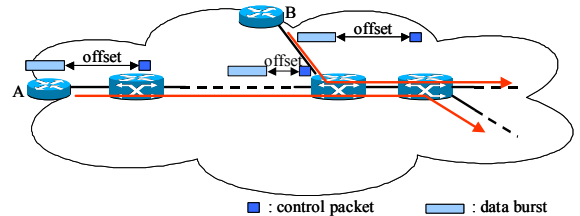
One direct result of this scheme is that the probability, that the bandwidth already used in the upstream nodes will be wasted, also increases as a burst nears its destination. Generally, when considering the overall efficiency of a network, it is desirable that a burst that has already consumed more resources be given priority to complete its transmission over those bursts that have already consumed less. However, the OT/DR-based scheme can cause the opposite effect in reserving wavelength. That is, in the OT/DR-based scheme, the burst blocking probability at each node will increase as the burst traverses the OBS nodes. Therefore, the OT/DR-based scheme degrades the end-to-end throughput in multiple hop network environments. This unintentional path length priority effect also complicates the use of extra QoS offset time for service differentiation in the OT/DR-based scheme.

IV. THE PROPOSED FDL/DR WITH HPI SCHEME

Due to the path length priority effect, the OT/DR-based schemes exhibit the higher burst blocking probability for a burst that is closer to its destination node. In contrast, the FDL/DR-based scheme can maintain a constant offset between the data burst and its control packet at each node, thereby resulting in no unintentional discrimination in wavelength reservation as a function of the remaining number of hops. Since a burst has generally a long size and a burst blocking wastes the bandwidth of the upstream nodes already consumed on its path, it is desirable that a burst that has traversed more nodes should have higher priority in contending for wavelength than those earlier in their transmission path. Adopting such a policy will enhance overall throughput in multiple hop network environments.

We propose a novel FDL/DR with HPI scheme in order to improve the end-to-end throughput. The basic concept of the FDL/DR with HPI scheme is shown in Fig. 3. The key idea of the FDL/DR with HPI scheme is to increase the priority of a burst hop-by-hop using an extra delay ΔT at each core node. In the proposed scheme, each node uses an input FDL to delay a burst by the amount of the processing time δ plus an extra delay ΔT. Thus, the total offset between the burst and its control packet will increase by ΔT whenever the burst traverses a node. In reserving wavelength, this accumulated offset plays the same role to increase priority as the extra QoS
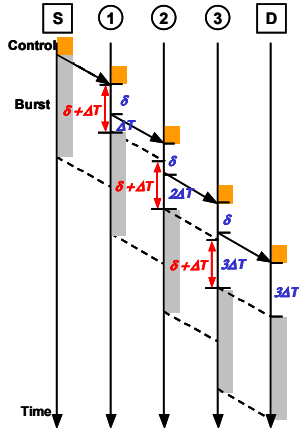
offset time in the JET scheme [5]. In other words, the priority of a burst increases automatically hop-by-hop as it traverses each node. Therefore, the proposed scheme guarantees a relatively lower burst blocking probability for bursts that have traversed more hops, resulting in enhancing the total end-to-end throughput in multiple hop network environments.

However, since the extra delay ΔT increases the end-to-end burst transfer delay, ΔT should be limited within the end-to-end burst delay requirements. Also, in order to support multiple classes of service, an extra QoS offset time can be assigned at the source node similar to the JET scheme. In this case, ΔT should be determined to avoid any inversion in service differentiation among the classes.

V. PERFORMANCE EVALUATION

Prior works have demonstrated the effect of the offset time and compared performance of existing OBS protocols in single hop networks [1],[6]-[7]. However, the performance of OBS protocols in multiple hop networks has not yet been sufficiently investigated. Accordingly, this section investigates the path length priority effect of the OT/DR-based scheme like the JET scheme in multiple hop network environments through simulation. Also, we compare the FDL/DR with HPI scheme with the existing schemes.

A. Simulation model

In order to investigate the path length priority effect and the end-to-end performance of the wavelength reservation schemes for OBS in multiple hop network environments, we consider a multiple hop network model with ring topology as shown in Fig. 4. In this model, it is assumed that S_1 - S_{10} are the source nodes and D_1 - D_{10} are their corresponding destination nodes in the OBS networks. The dotted lines indicate the example paths for transmitting the bursts to their destinations. Hence, every burst traverses 5 hops from the source OBS node to the destination OBS node. In this configuration, the bursts with different number of remaining hops (from 1 to 5 hops) to their destination OBS nodes contend for reserving wavelength at each link. Also, each link is assumed as consisting of four WDM wavelengths operating at 10Gbps, and one wavelength is used for the control channel.
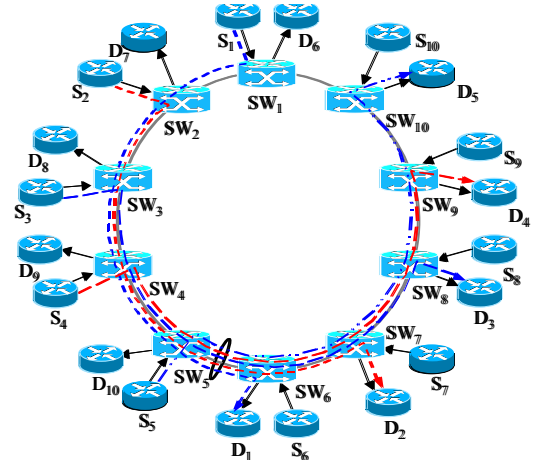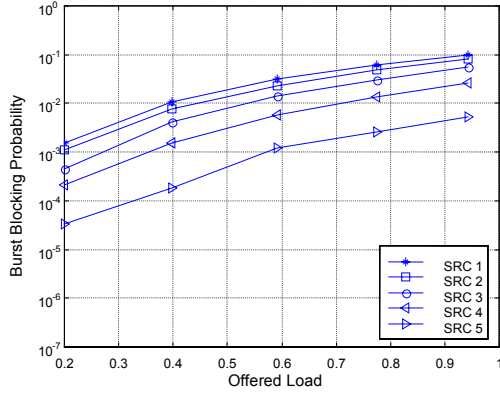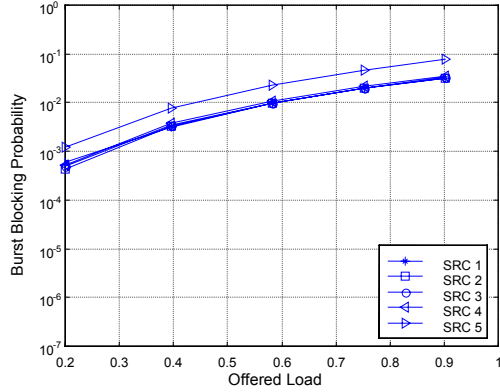

Fig. 3. Basic concept of the proposed FDL/DR with HPI scheme.

Fig. 4. Network configuration for simulation.

(a) JET scheme

(b) FDL/DR-based scheme

Fig. 5. Comparison of the burst blocking probabilities at SW_5.

The processing time of the control packet plus the switch setup time in each core node is assumed as δ=10μsec. And, full wavelength conversions among the data channels are assumed at the OBS nodes. Each source generates the bursts according to an on/off model. The burst length is assumed to be exponentially distributed with an average of 100Kbits. The offered loads of each link are controlled by changing the inter-arrival time of the bursts. We consider ΔT =5μsec for the FDL/DR with HPI scheme.

B. Simulation results and discussion

First, in order to investigate the path length priority effect, we compare the burst blocking probabilities at SW_5 for the sources $S_1 \sim S_5$.

Fig. 5(a) shows the burst blocking probability of the JET with the OT/DR-based scheme. This figure illustrates that the sources $S_1 \sim S_5$ experience different burst blocking probabilities as if they have different priority classes. This is due to the fact that even though all bursts are assigned the same basic offset time at each source node, they have different residual offset times at SW_5 because of the different number of OBS nodes have traversed. From this figure, we note that the OT/DR-based schemes cause the path length

priority effect in multiple hop network environments.

Fig. 5(b) shows the burst blocking probability of the FDL/DR-based scheme. In this figure, we can see that this scheme produces the similar burst blocking probabilities for all bursts regardless of the remaining number of hops to their destinations. One peculiar feature is that the burst blocking probability of S_5 is a little bit higher than those of the other sources. This is due to the fact that the bursts from S_5 contend with all the other bursts from $S_1 \sim S_4$ at SW_5, while the bursts from $S_1 \sim S_4$ are already aligned in stream at the previous nodes and do not contend each other at SW_5 in this network configuration. Therefore, we note that the FDL/DR-based scheme can avoid the path length priority effect, which is the problem of the OT/DR-based schemes.

Next, we compare the end-to-end performance of the FDL/DR with HPI scheme with the existing schemes in terms of the burst blocking probabilities at each hop and the end-to-end throughput.

Fig. 6(a) shows the burst blocking probabilities at each OBS node when the offered load intensities at each OBS node are about 0.8. In this figure, the JET scheme exhibits that the burst blocking probability at each hop increases gradually as the burst traverses the OBS nodes due to the path length priority effect. In contrast, the FDL/DR-based scheme shows almost the same burst blocking probabilities at each transit node irrespective of the remaining hops to its destination. Meanwhile, the FDL/DR with HPI scheme exhibits that the burst blocking probability is the highest at the first hop and decreases at each hop as the burst nears its destination. Therefore, this scheme provides that a burst traversed more hops can complete its transmission successfully. Also, this scheme has inherently an ability of burst admission control, because it can block a new burst to be admitted into the network at the first hop when the offered load is excessive.
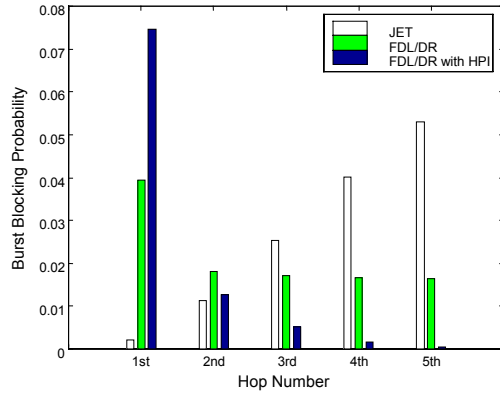
Fig. 6(b) compares the cumulative burst blocking probabilities at each hop for the same traffic load condition as in Fig. 6(a). This figure shows that compared with the other two schemes, the FDL/DR with HPI scheme exhibits the lowest overall burst blocking probability, even though it has the highest burst blocking probability at the first hop.

From these results of Fig. 6(a) and (b), we therefore expect that the FDL/DR with HPI scheme can improve the end-to-end throughput by reducing the bandwidth waste by dropped bursts.

Fig. 6(c) shows the total end-to-end throughput versus the offered load intensity. The JET scheme exhibits the lowest throughput due to the path length priority effect, while the FDL/DR with HPI scheme gives the best performance in the end-to-end throughput. In this example, when the offered load intensity is about 0.8, the FDL/DR with HPI scheme can improve the throughput by 10% over the JET scheme. And, we note that its improvements in the end-to-end throughput are more remarkable at the higher offered load condition.

VI. CONCLUSION

In this paper, we classified the wavelength reservation mechanisms of OBS, and investigated the path length priority effect of the OT/DR-based scheme like the JET protocol. And, we showed that the FDL-based scheme can avoid the path length priority effect in multiple hop network environments.

(a) Burst blocking probability
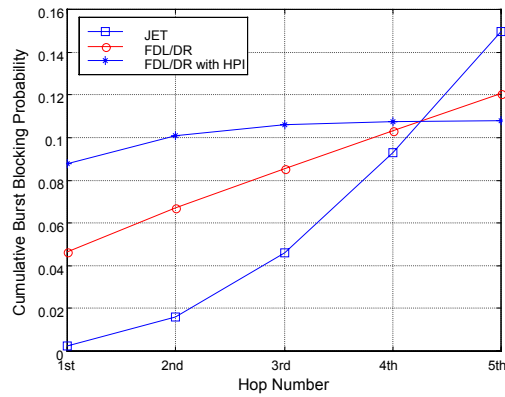
(b) Cumulative burst blocking probability
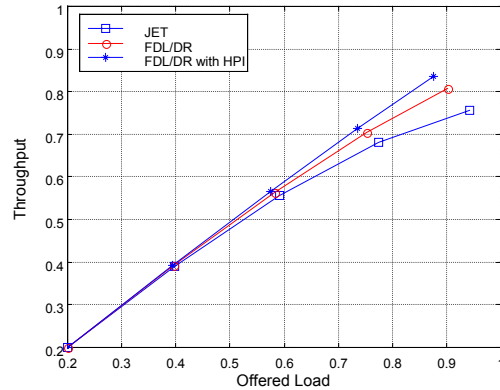
(b) Throughput

Fig. 6. Comparison of the end-to-end performance.

Also, we proposed a novel FDL/DR with HPI scheme which can improve the end-to-end throughput by increasing the priority of bursts hop-by-hop using the input FDLs at each node. The simulation results showed that the proposed FDL/DR with HPI scheme can avoid the path length priority effect and enhance the end-to-end throughput in multiple hop network environments.

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